UNCLASSIFIED

AD NUMBER

AD843077

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; OCT 1968. Other requests shall be referred to Office of Naval Research, Washington, DC 20360. This document contains export-controlled technical data.

AUTHORITY

onr notice, 27 jul 1971

THIS PAGE IS UNCLASSIFIED

HPC 68-72

AD843077

MONSANTO/WASHINGTON UNIVERSITY
ONR/ARPA ASSOCIATION

MECHANICAL PROPERTIES OF TAPE COMPOSITES

P. E. Chen and L. E. Nielsen

October 1968

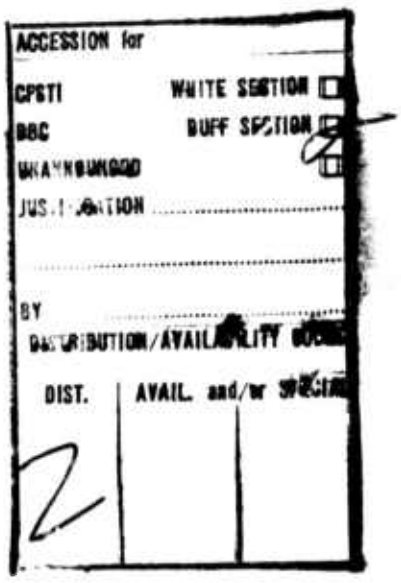
PROGRAM MANAGER

ROLF BUCHDAHL

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Director of Material Sciences, Office of Naval Research.

MONSANTO RESEARCH CORPORATION
A SUBSIDIARY OF MONSANTO COMPANY
800 N. LINDBERGH BOULEVARD ST. LOUIS, MISSOURI 63166

DDC
RETURNED
NOV 13 1968



NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurment operation, the United States Government thereby incurs no responsibiliy nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

DDC release to CFSTI is not authorized.

HPC 68-72

MONSANTO/WASHINGTON UNIVERSITY
ONR/ARPA ASSOCIATION

MECHANICAL PROPERTIES OF TAPE COMPOSITES

P. E. Chen and L. E. Nielsen

October 1968

Program Manager
Rolf Buchdahl

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Director of Material Sciences, Office of Naval Research.

Monsanto Research Corporation
800 North Lindbergh Blvd.
St. Louis, Missouri 63166

FOREWORD

The research reported herein was conducted by the staff of the Monsanto/Washington University Association under the sponsorship of the Advanced Research Projects Agency, Department of Defense, through a contract with the Office of Naval Research, N00014-67-C-0218 (formerly N00014-66-C-0045), ARPA Order No. 873, ONR contract authority NR 356-484/4-13-66, entitled "Development of High Performance Composites."

The prime contractor is Monsanto Research Corporation. The Program Manager is Dr. Rolf Buchdahl (phone 314-694-4721).

The contract is funded for $5,000,000 and expires 30 April 1970.

ABSTRACT

The stiffness and strength of tape-reinforced composites have been calculated by using the finite-element method, simple model theory and the von Mises-Hencky criterion. The tapes are assumed to be oriented uniaxially in both the longitudinal and transverse directions. According to the theoretical calculations, substantial increases in two basic moduli and a transverse strength are possible with the tape systems, as compared with the corresponding fiber systems. The calculations are based mainly on glass-epoxy composites.

INTRODUCTION

A great deal of literature [1-7] has been published concerning the mechanical properties of fiber and particulate-reinforced composites, but relatively scanty information is available on such properties for the tape-reinforced composites which are characterized by the class of reinforcements with parallel faces. In order to establish the practical potentialities of the tape composites, theoretical studies have been made on the stiffness and strength of such systems. The tapes are assumed to be uniaxially aligned both in the longitudinal and transverse directions, and ideally packed into staggered configuration in cross section as shown in Figure 1.

The longitudinal modulus and strength of the tape composites are essentially the same as those of the corresponding fiber composites. The other five basic elastic moduli and the two transverse strengths have been calculated for the tape composites and compared with those for the corresponding fiber composites. The fibers in the reference composite systems are assumed to be circular in cross section, uniaxially aligned, and packed into hexagonal arrays. Two limiting conditions have been considered in the strength calculations. For the first condition the reinforcing phase is assumed to be perfectly bonded to the matrix, while for the second condition it is assumed to be totally debonded from the matrix, thus providing the upper and lower bounds.

The calculations are based mainly on the glass-epoxy systems because of the commercial availability of the glass tapes. However, some calculations have been made also on boron-epoxy systems for comparison's sake.

THEORY

Elastic Moduli

Uniaxially oriented tape composites are anisotropic and require six elastic moduli to describe their stiffness characteristics. These elastic moduli are illustrated in Figure 2 in which E_L, E_T and E_{TT} are Young's moduli, while G_{LT}, $G_{LT'}$ and G_{TT} are shear moduli. The subscripts L and T refer to the longitudinal and transverse directions respectively.

The finite-element method [8-10] is utilized to calculate the stresses and displacements in the composite, which in turn are used to evaluate the elastic moduli from their basic definitions. Based on this method, an elastic system is first divided into a number of discrete elements joined together at the nodes. The basic equations of elasticity can be written for each of the elements within the system, which relate the forces acting on the nodes to the displacements of the nodes. These equations can then be correlated through a set of relations representing the simple fact that the elements must fit together, which is usually referred to in elasticity theory as the compatibility condition.

A typical region as shown in Figure 3 can be used to calculate the transverse moduli of the tape composites. To calculate the transverse modulus E_T (parallel to the widths of the tapes) for the tape composites, the finite-element

method is first applied to the typical region and the procedure given in the Appendix is used to calculate the distributions of stress and displacement in the region. Corresponding to the superimposed case as given in the Appendix, the applied normal stress (parallel to the widths of the tapes) can be calculated from the stress distribution thus determined. The modulus is obtained by a simple application of the Hooke's law. The transverse modulus E_{TT} (perpendicular to the widths of the tapes) of the tape composites can be calculated in a similar manner except that the normal load is now applied in the y-direction, and the boundary conditions for Cases 1 and 2 as well as the equation for superposition in Case 3 as given in the Appendix are changed accordingly.

The transverse modulus E_T or E_{TT} of the fiber composites are calculated based on the formulas given in References 1 and 11.

The transverse shear modulus G_{TT} (parallel and perpendicular to the widths of the tapes) of the tape composites can be calculated by considering the same typical region as mentioned previously, except using the boundary conditions corresponding to those of the pure shear and governed by compatibility of the composite domain. The longitudinal-transverse shear moduli G_{LT} (with the longitudinal axis parallel to the lengths of the tapes, and the transverse axis parallel to their widths) and G_{LT}' (with the longitudinal axis parallel to the lengths of the tapes, and the transverse axis perpendicular to their widths) of the tape composites are calculated under the same

boundary conditions as those used for G_{TT}, but with different typical regions taken in the longitudinal direction. The moduli G_{TT}, G_{LT} and $G_{LT'}$ are calculated from the basic definition of the shear modulus.

In the limiting case where the width w of the tape is much greater than its thickness t (i.e., $w/t \to \infty$), then the elastic moduli can be calculated from equations derived from the simple models consisting of laminated structures. Figure 3 illustrates the models used in this limiting case. For the moduli E_L, E_T and G_{LT}, both phases experience the same deformation, so that the moduli are directly proportional to the constituent moduli and the relative proportion of each phase. For the moduli E_{TT}, $G_{LT'}$ and G_{TT}, the less stiff matrix phase undergoes more deformation than the more rigid tapes; compliances, i.e., reciprocal moduli, are additive in this case. The equations, which yield either upper or lower bounds, for the moduli are as follows:

$$E_L = E_T = E_m V_m + E_f V_f \tag{1}$$

$$\frac{1}{E_{TT}} = \frac{V_m}{E_m} + \frac{V_f}{E_f} \tag{2}$$

$$G_{LT} = G_m V_m + G_f V_f \tag{3}$$

$$\frac{1}{G_{LT'}} = \frac{1}{G_{TT}} = \frac{V_m}{G_m} + \frac{V_f}{G_f} \tag{4}$$

where V_m and V_f are the volume fractions of the matrix and tape phases respectively.

As for fiber composites, the transverse shear moduli G_{TT} and G_{LT}, are calculated from the formula given in Reference 1, and the longitudinal-transverse shear modulus G_{LT} from the formula derived in Reference 5.

Transverse Strengths

Various theories [12-15] have been proposed for predicting the strength of materials. However, the theory introduced by von Mises [16] and reinterpreted by Hencky [17] is generally recognized as conceptually most consistent, and it is also supported by experimental evidences.

The total strain energy stored in an elastic body can be divided into two parts, the dilatational energy and the distortional energy, with the former being the energy used in changing the volume and the latter being the energy used in changing the shape [12,13]. The von Mises-Hencky theory postulates that yielding sets in when the distortional energy reaches a critical value. For a uniaxial and plane state of stress the criterion becomes

$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 = S_m^2 \qquad (5)$$

where σ_1 and σ_2 are the principal stresses, and S_m is the strength of the matrix material. The quantity on the left side of equation (5) will be referred to as the normalized distortional energy hereafter.

The von Mises-Hencky criterion has been used to calculate the transverse strengths of tape composites. Based on

the stress distributions obtained previously for E_T, the normalized distortional energy is evaluated for every element in the domain, thus determining also the maximum normalized distortional energy. The transverse strength S_T (parallel to the widths of the tapes) of the tape composites can then be calculated from the following equation:

$$S_T = S_m \, \bar{\sigma}_x / (U_{max})^{1/2} \qquad (6)$$

where $\bar{\sigma}_x$ is the applied normal stress in the x-direction (see Figure 4) under the assumed displacement conditions as described in the Appendix, and U_{max} is the corresponding maximum normalized distortional energy. Both $\bar{\sigma}_x$ and U_{max} are functions of the filler volume content, condition of bonding, as well as the constituent properties. Further, by using the stress distributions calculated before for E_{TT}, the transverse composite strength S_{TT} (perpendicular to the widths of the tapes) for the tape composites can be calculated in a similar manner from the following equation:

$$S_{TT} = S_m \, \bar{\sigma}_y / (U'_{max})^{1/2} \qquad (7)$$

where $\bar{\sigma}_y$ is the applied normal stress in the y-direction under the assumed displacement conditions for E_{TT}, and U'_{max} is the corresponding maximum normalized distortional energy.

The transverse strengths of the fiber composites are calculated based on the method proposed in Reference 18. Moreover, both the tape and fiber composite strengths have been calculated for the conditions of perfect bonding and total

debording. For the condition of perfect bonding the fillers are assumed to be in perfect contact with the matrix, and the composite is considered continuous, from the mechanistic point of view, at the interface between the constituents. For the condition of total debonding the fillers are assumed to be completely separated from the matrix.

RESULTS AND DISCUSSION

The theoretical approaches as described above were used to calculate the mechanical properties of tape composites as functions of filler volume content V_f, and compared to those for fiber composites. Variations of the moduli E_T, E_{TT}, G_{LT}, G_{LT}, and G_{TT} versus filler volume content V_f are shown in Figures 5, 6, 7, 9 and 10 respectively for glass-epoxy tape and fiber composites. Figure 8 shows the variations of G_{LT} versus V_f for boron-epoxy tape and fiber composites. The normalized moduli E_T / E_m and G_{LT} / G_m are shown in Figures 11 through 14 as functions of the tape width to thickness ratio w/t and filler volume content V_f for glass-epoxy and boron-epoxy tape composites. The transverse strengths S_T and S_{TT} are shown in Figures 15 through 18 as functions of filler volume content for glass-epoxy tape and fiber composites, and for different bonding conditions. Except for Figures 11 through 14, the tapes are assumed to be 0.125 in. x 0.003 in. in cross section.

As can be observed from their respective figures, it is possible for the tape composites to achieve substantial increases in the transverse modulus E_T, shear modulus G_{LT} and transverse strength S_T, as compared to the corresponding fiber composites. For glass-epoxy systems, the maximum increases are as follows: 250% in E_T, 340% in G_{LT} and S_T. If boron tapes with the same w/t ratio were used, the increases would

have been even higher, for instance, a maximum increase of 1,950% is G_{LT} is possible with such tape systems. Moreover, from the geometric point of view, it is possible for the filler volume content in the tape system to reach 100% while 90.6% is the upper limit for the fiber system, thus further enhancing the above-mentioned properties. However, it should also be pointed out that accompanying such increases there are slight decreases in the other three moduli, E_{TT}, $G_{LT'}$ and G_{TT}. Under the condition of total debonding the transverse strength S_T of the tape composite is slightly higher, as compared with the corresponding fiber composite. For the case of perfect bonding the transverse strength S_{TT} of the tape composite equals the matrix strength, which is also slightly higher than the S_{TT} of the corresponding fiber composite. In addition, under the condition of total debonding, the transverse composite strength S_{TT} drops sharply to zero as soon as some tapes are embedded into the matrix. Thus the significance of bonding can not be overemphasized.

It is interesting to see from Figures 11 through 14 that insofar as E_T and G_{LT} are concerned, the asymptotic values (corresponding to large w/t values) are practically reached when w/t = 100.

Perhaps, it should also be emphasized that the basis of strength of the tape composite lies in the staggered packing arrangement as shown in Figure 1, which provides an efficient shear transfer mechanism [19].

ACKNOWLEDGEMENTS

The work described in this paper was performed under the auspices of the Monsanto/Washington University Association sponsored by the Advanced Research Projects Agency under ONR Contract No. N00014-67-C-0218, formerly No. N00014-66-C-0045. The computer program used for carrying out the finite-element calculations was originally written by Professor E. L. Wilson of the University of California at Berkeley whose generosity is gratefully acknowledged. The assistance of Miss Barbara Krueger is greatly appreciated.

NOMENCLATURE

B_m = Bulk modulus of the matrix material.

E_f = Young's modulus of the filler material.

E_m = Young's modulus of the matrix material

E_L = Longitudinal composite modulus (parallel to the lengths of the tapes or fibers).

E_T = Transverse composite modulus (parallel to the widths of the tapes in the case of tape composites).

E_{TT} = Transverse composite modulus (perpendicular to the widths of the tapes in the case of tape composites).

G_f = Shear modulus of the filler material.

G_m = Shear modulus of the matrix material.

G_{LT} = Longitudinal-transverse composite shear modulus (with the longitudinal axis parallel to the lengths of the tapes, and the transverse axis parallel to their widths, in the case of tape composites).

$G_{LT'}$ = Longitudinal-transverse composite shear modulus (with the longitudinal axis parallel to the lengths of the tapes, and the transverse axis perpendicular to their widths, in the case of tape composites).

G_{TT} = Transverse composite shear modulus (parallel and perpendicular to the widths of the tapes in the case of tape composites).

S_m = Strength of the matrix material.

S_T = Transverse composite strength (parallel to the widths of the tapes in the case of tape composites).

S_{TT} = Transverse composite strength (perpendicular to the widths of the tapes in the case of tape composites).

ν_f = Poisson's ratio of the filler material.

ν_m = Poisson's ratio of the matrix material.

U_{max}, U_{max} = Maximum normalized distortional energies for applied normal stressses in x and y-directions (see Appendix).

V_f = Filler volume content.

V_m = Matrix volume content.

x, y = Rectangular coordinates.

u, v = Displacements in x and y-directions.

u_1, v_1 = Displacements in x and y-directions for Case 1 in the Appendix.

u_2, v_2 = Displacements in x and y-directions for Case 2 in the Appendix.

σ_1, σ_2 = Principal stresses.

$\bar{\sigma}_{x1}$ $\bar{\sigma}_{y1}$ = Average normal stresses in x and y-directions for Case 1 in the Appendix.

$\bar{\sigma}_{x_2}$, $\bar{\sigma}_{y_2}$ = Average normal stresses in x and y-directions for Case 2 in the Appendix.

$\bar{\sigma}_x$, $\bar{\sigma}_y$ = Average normal stresses in x and y-directions for Case 3 in the Appendix.

τ_{xy} = Shearing stress in xy-plane parallel to x or y-axis.

a, b = Width and length of the typical region.

w, t = Width and thickness of the tape.

F.E.M. = Results obtained by using the finite-element method (for $w/t = 41.7$).

S.M.T. = Results obtained by using the simple model theory (for $w/t \to \infty$).

REFERENCES

1. J. J. Hermans, "The Elastic Properties of Fiber-Reinforced Materials When the Fibers Are Aligned," Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, Proceedings, Series B, Vol. 70, No. 1 (1967), p. 1.

2. L. B. Greszczuk, "Theoretical and Experimental Studies on Properties and Behavior of Filamentary Composites," Proceedings of the 21st Annual Conference of the Reinforced Plastics Division, Society of Plastics Industry, Section 8-A (1966).

3. D. F. Adams, D. R. Doner and R. L. Thomas, "Mechanical Behavior of Fiber-Reinforced Composite Materials," AFML-TR-67-96 (May 1967), Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

4. S. W. Tsai, "Formulas for the Elastic Properties of Fiber-Reinforced Composites," AFML Review of Mechanics of Composite Materials for Air Force Contractors (Jan. 1968), Air Force Materials Laboratory.

5. Z. Hashin and B. W. Rosen, "The Elastic Moduli of Fiber-Reinforced Materials," J. Applied Mechanics, Vol. 31 (June 1964), p. 223.

6. R. Hill, "Theory of Mechanical Properties of Fibre-Strengthened Materials: I. Elastic Behavior," J. Mech. Phys. Solids, Vol 12 (1964), p. 199.

7. J. M. Whitney and M. B. Riley, "Elastic Stress-Strain Properties of Fiber Reinforced Composite Materials," AFML-TR-65-238 (Dec. 1965), Air Force Materials Laboratory.

8. M. J. Turner, R. W. Clough, H. C. Martin and L. J. Topp, "Stiffness and Deflection Analysis of Complex Structures," J. Aeronautical Sciences, Vol. 23 (1956), p. 805.

9. R. W. Clough, "The Finite Element Method in Plane Stress Analysis," NSF Report, Research Grant G-7337 (1960).

10. H. C. Martin, "Plane Elasticity Problems and the Direct Stiffness Method," The Trend in Engineering, University of Washington (1961), p. 5.

11. S. W. Tsai, "Structural Behavior of Composite Materials," NASA Contractor Report CR-71 (July 1964), National Aeronautics and Space Administration.

12. A. Nadai, Theory of Flow and Fracture of Solids, McGraw-Hill (1950), New York.

13. O. Hoffman and G. Sachs, Introduction to the Theory of Plasticity for Engineers, McGraw-Hill (1953), New York.

14. R. Hill, The Mathematical Theory of Plasticity, Oxford University Press (1950), London.

15. W. Prager, An Introduction to Plasticity, Addison-Wesley (1959), London.

16. R. von Mises, "Mechanik der festen Körper im plastisch deformablen Zustand," Göttinger Nachrichten, math.-phys. Klasse (1913), S. 582.

17. H. Hencky, "Zur Theorie plastischer Deformationen und der hierdurch im Material hervorgerufenen Nachspannungen," Zeits. angew. Math. Mech., Bd. 4 (1924), S. 323.

18. P. E. Chen and J. M. Lin, "Transverse Properties of Fibrous Composites," Contribution HPC 68-70 from the Monsanto/Washington University ONR/ARPA Association, "High Performance Composites," St. Louis, Missouri, Contract ONR No. N00014-67-C-0218, formerly Contract ONR No. N00014-66-C-0045, (1968).

19. M. A. Sadowsky, "Transfer of Force by High-Strength Flakes in a Composite Material," Technical Report WVT-RR-6105-R (June 1961), Army Watervliet Arsenal, Watervliet, New York.

20. S. W. Tsai, D. F. Adams and D. R. Doner, "Effect of Constituent Material Properties on the Strength of Fiber-Reinforced Composite Materials," AFML-TR-66-190 (Aug. 1966), p. 38, Air Force Materials Laboratory.

APPENDIX

The determination of the stress and displacement distributions in a transverse composite domain as shown in Figure 1 can be accomplished by analyzing a typical region, as shown in Figure 4. The procedure used here is basically similar to that described in Reference 20. In conjunction with the evaluation of E_T and S_T, the finite-element technique and the method of superposition are used to solve the problem in the following steps, assuming that the applied normal stress is in the x-direction:

1. Solve Case 1 which is defined by the following boundary conditions:

$\tau_{xy} = 0$ along the entire boundary,

$u = 0$ along AO (points remain on the y-axis because of symmetry),

$u = 1$ along BC (arbitrarily specified unit displacement),

$v = 0$ along OC (points remain on the x-axis because of symmetry),

$v = 0$ along AB (specified displacement condition).

The displacement field thus calculated is (u_1, v_1), and the average normal stresses in the x and y-directions are $\bar{\sigma}_{x1}$ and $\bar{\sigma}_{y}$, respectively.

2. Solve Case 2 which is defined by the following boundary conditions:

$\tau_{xy} = 0$ along the entire boundary,

$u = 0$ along AO,

$u = 0$ along BC,

$v = 0$ along OC,

$v = 1$ along AB.

The displacement field thus calculated is (u_2, v_2) and the average normal stresses in the x and y-directions are $\bar{\sigma}_{x2}$ and $\bar{\sigma}_{y2}$ respectively.

3. Solve Case 3 which is characterized by $\bar{\sigma}_y = 0$, solution of Case 2 is multiplied by $(-\bar{\sigma}_{y1} / \bar{\sigma}_{y2})$ and summed with that of Case 1. Thus the corresponding applied normal stress on the composite is

$$\bar{\sigma}_x = \bar{\sigma}_{x1} - \frac{\bar{\sigma}_{y1}}{\bar{\sigma}_{y2}} \bar{\sigma}_{x2} \quad . \tag{8}$$

Likewise for the stress and displacement components.

LIST OF FIGURES

Figure 1. Idealized tape composite.

Figure 2. Basic elastic moduli of a tape composite.

Figure 3. Simple models for the limiting case of tape composites.

Figure 4. Typical region.

Figure 5. Transverse modulus E_T as a function of filler volume content V_f for glass-epoxy tape and fiber composites.

Figure 6. Transverse modulus E_{TT} as a function of filler volume content V_f for glass-epoxy tape and fiber composites.

Figure 7. Longitudinal-transverse shear modulus G_{LT} as a function of filler volume content V_f for glass-epoxy tape and fiber composites.

Figure 8. Longitudinal-transverse shear modulus G_{LT} as a function of filler volume content V_f for boron-epoxy tape and fiber composites.

Figure 9. Longitudinal-transverse shear modulus G_{LT}' as a function of filler volume content V_f for glass-epoxy tape and fiber composites.

Figure 10. Transverse shear modulus G_{TT} as a function of filler volume content V_f for glass-epoxy tape and fiber composites.

Figure 11. Normalized transverse modulus E_T / E_m as a function of tape width to thickness ratio w/t and filler volume content V_f for glass-epoxy tape composites.

Figure 12. Normalized transverse modulus E_T / E_m as a function of tape width to thickness ratio w/t and filler volume content V_f for boron-epoxy tape composites.

Figure 13. Normalized longitudinal-transverse shear modulus G_{LT} / G_m as a function of tape width to thickness ratio w/t and filler volume content V_f for glass-epoxy tape composites.

Figure 14. Normalized longitudinal-transverse shear modulus G_{LT} / G_m as a function of tape width to thickness ratio w/t and filler volume content V_f for boron-epoxy tape composites.

Figure 15. Transverse strength S_T as a function of filler volume content V_f for glass-epoxy tape and fiber composites, assuming matrix strength = 6,000 psi.

Figure 16. Transverse strength S_{TT} as a function of filler volume content V_f for glass-epoxy tape and fiber composites, assuming matrix strength = 6,000 psi.

Figure 17. Transverse strength S_T as a function of filler volume content V_f for glass-epoxy tape and fiber composites, assuming matrix strength = 13,000 psi.

Figure 18. Transverse strength S_{TT} as a function of filler volume content V_f for glass-epoxy tape and fiber composites, assuming matrix strength = 13,000 psi.

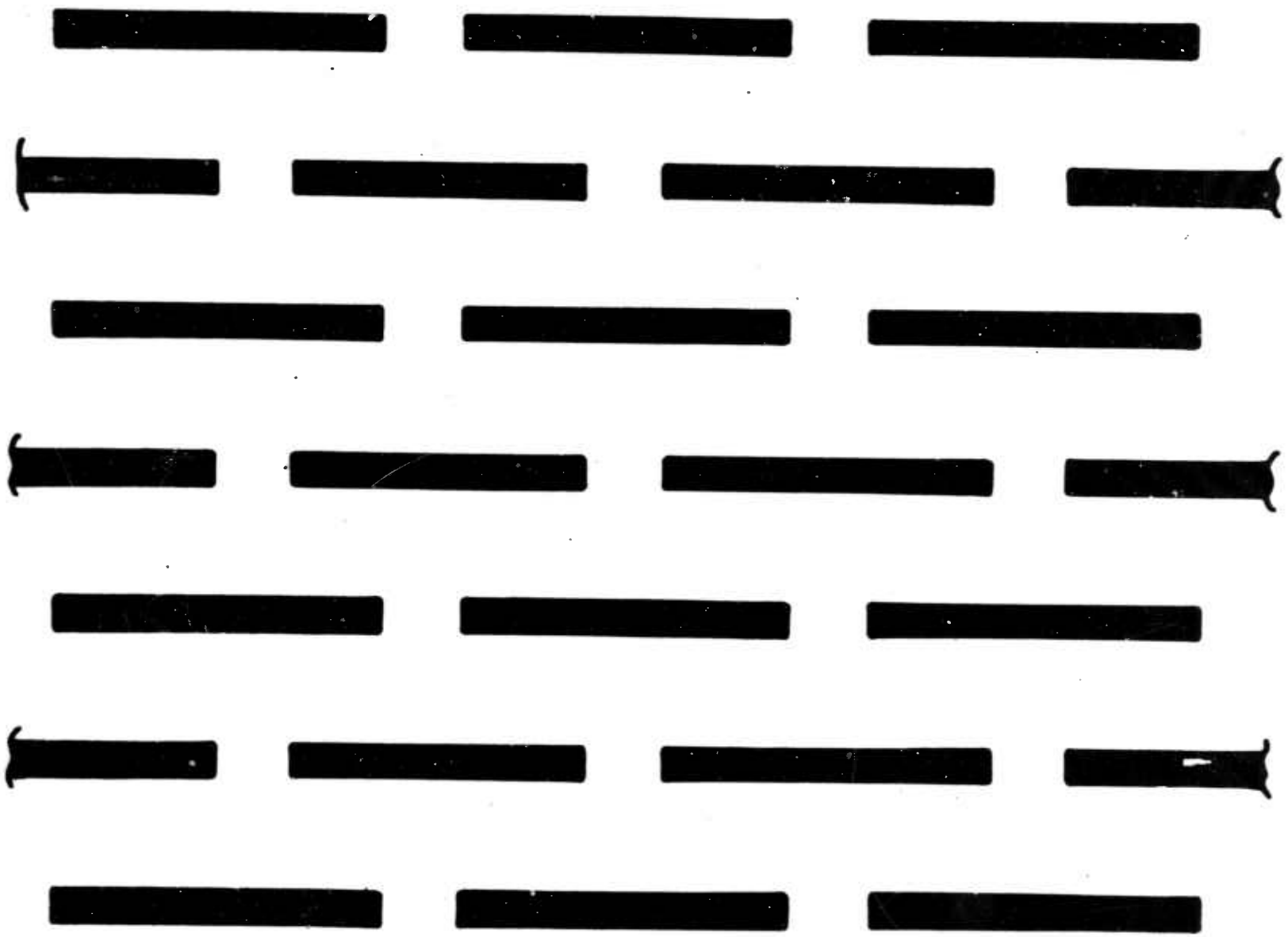


Figure 1

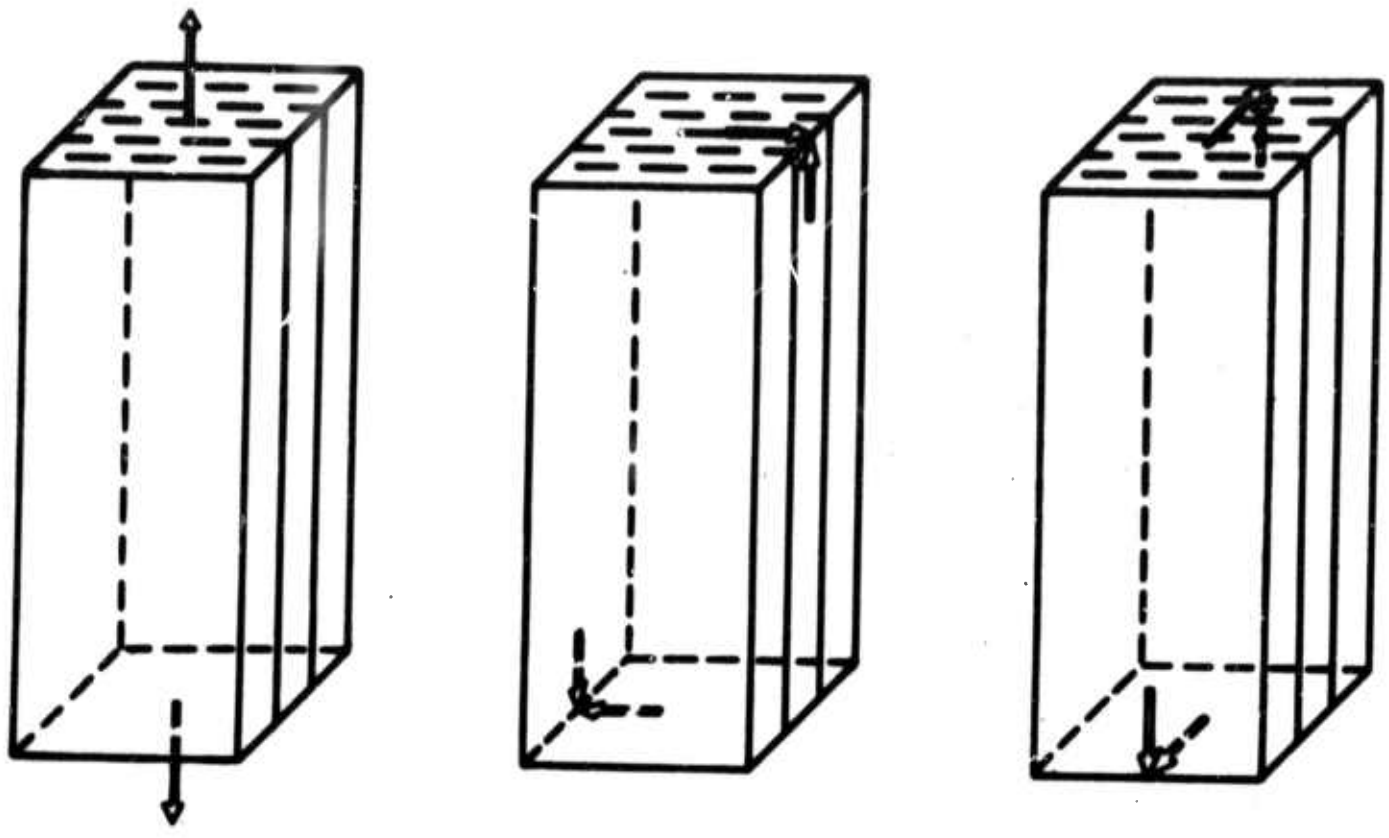
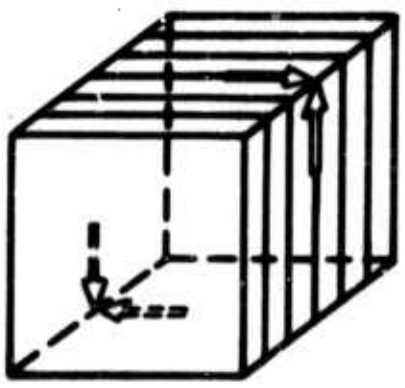


Figure 2

E_{TT}

$E_L = E_T$



G_{LT}

$G_{LT'} = G_{TT}$

Figure 3

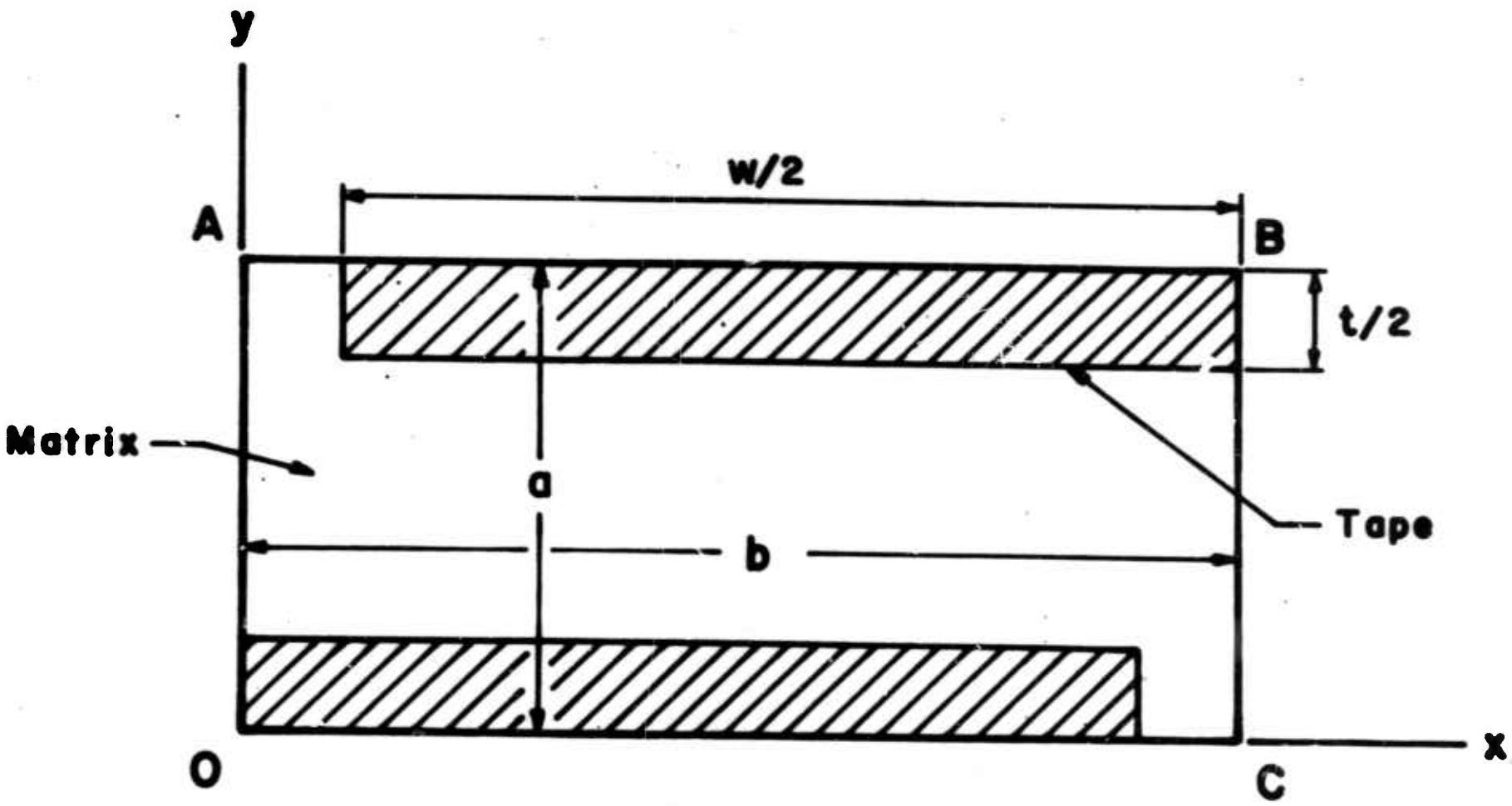


Figure 4

GLASS-EPOXY COMPOSITES

$E_f = 10.6 \times 10^6$ psi, $\nu_f = 0.22$

$E_m = 0.5 \times 10^6$ psi, $\nu_m = 0.35$

F.E.M. = Finite-Element Method

S.M.T. = Simple Model Theory

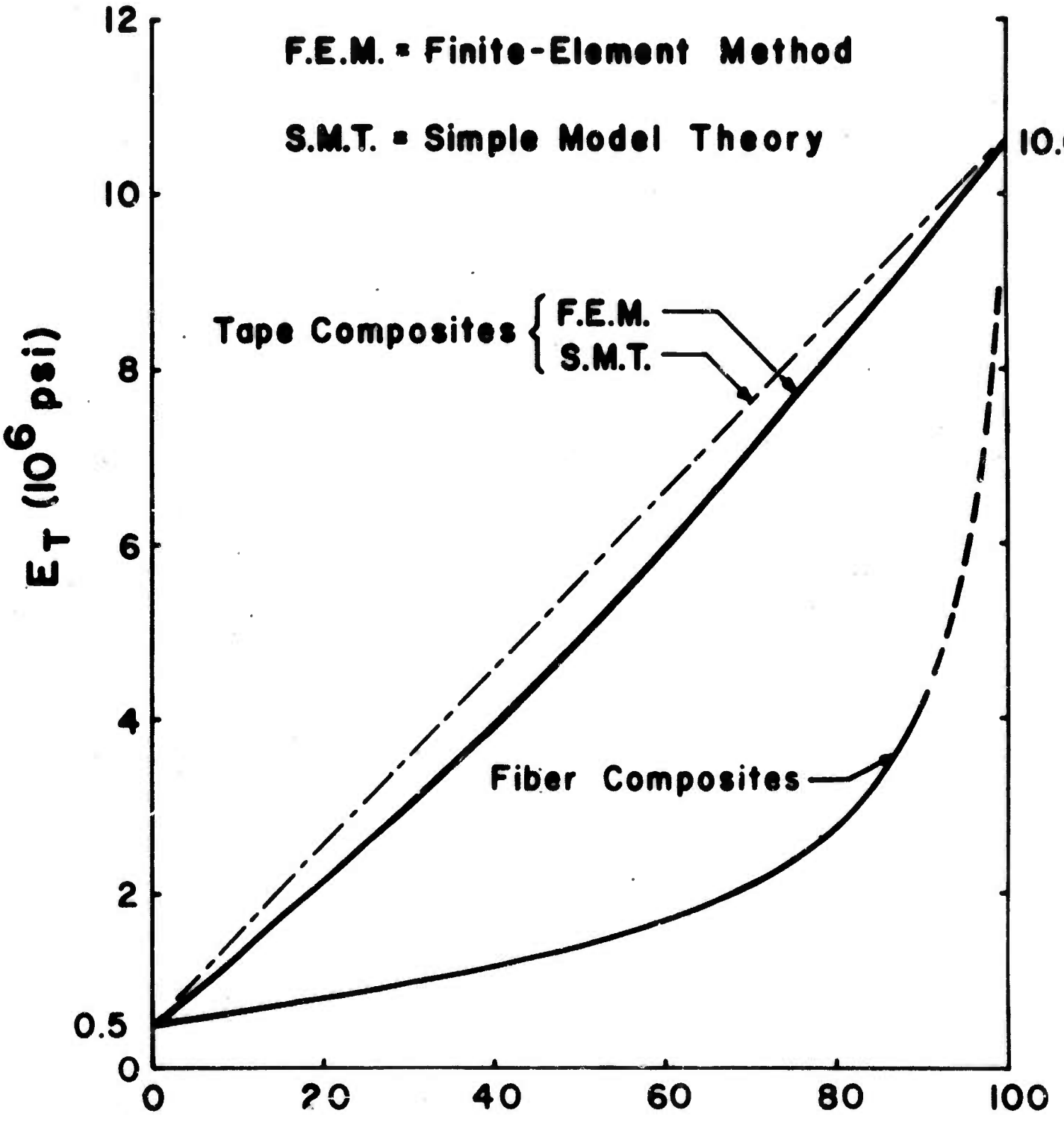


Figure 5

GLASS-EPOXY COMPOSITES

$E_f = 10.6 \times 10^6$ psi, $\nu_f = 0.22$

$E_m = 0.5 \times 10^6$ psi, $\nu_m = 0.35$

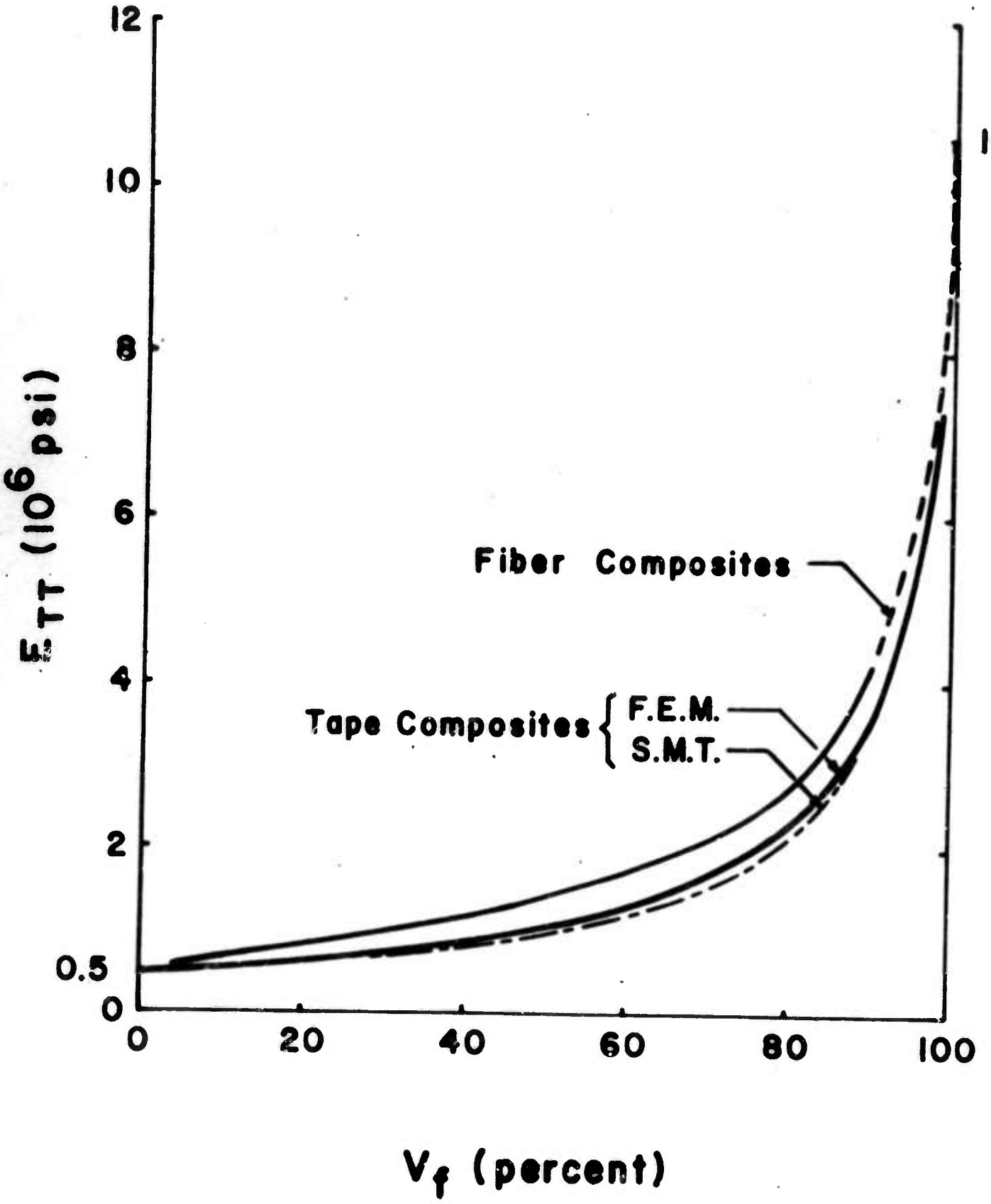


Figure 6

GLASS-EPOXY COMPOSITES

$G_f = 4.34 \times 10^6$ psi, $\nu_f = 0.22$

$G_m = 0.185 \times 10^6$ psi, $\nu_m = 0.35$

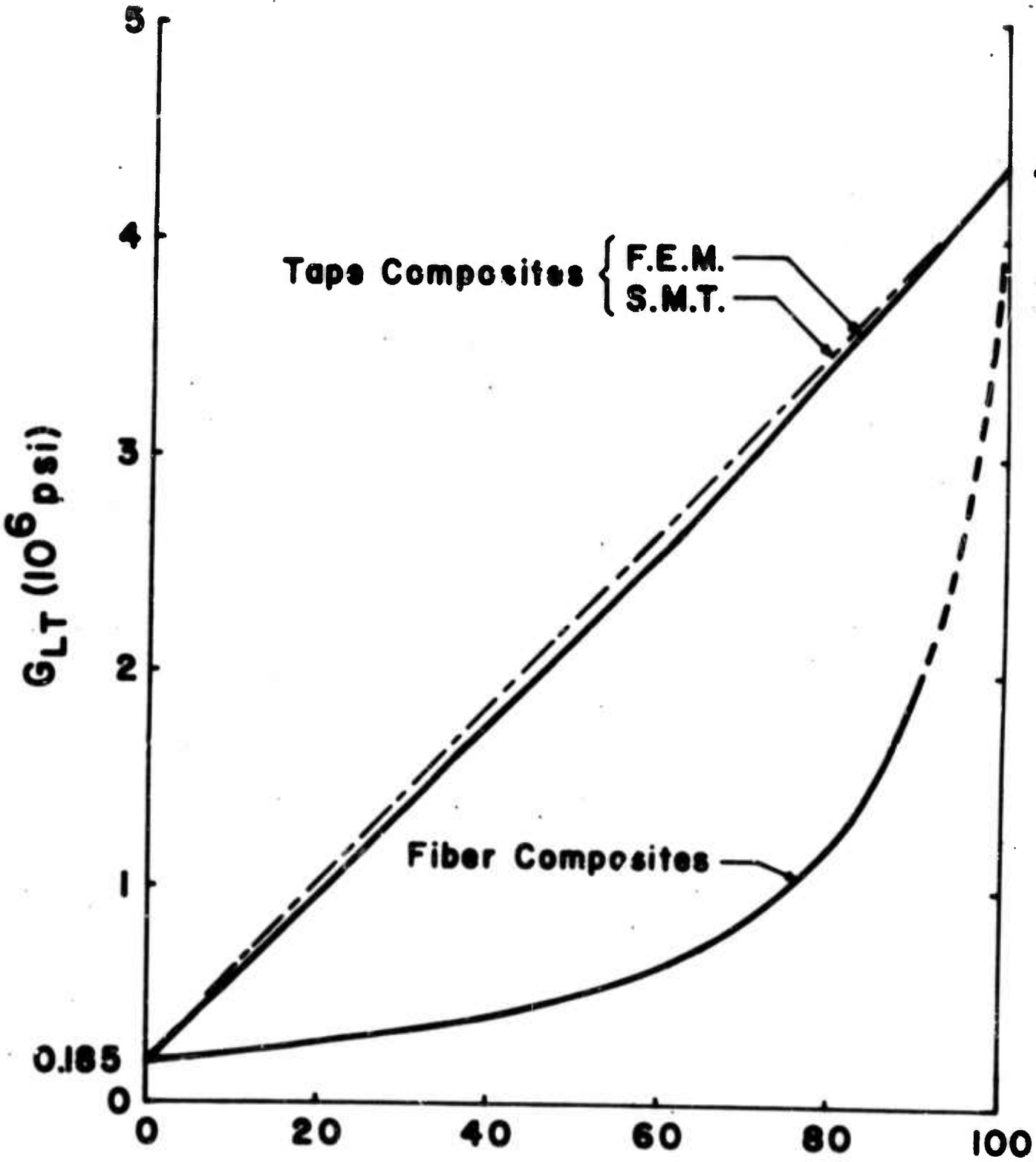


Figure 7

BORON-EPOXY COMPOSITES

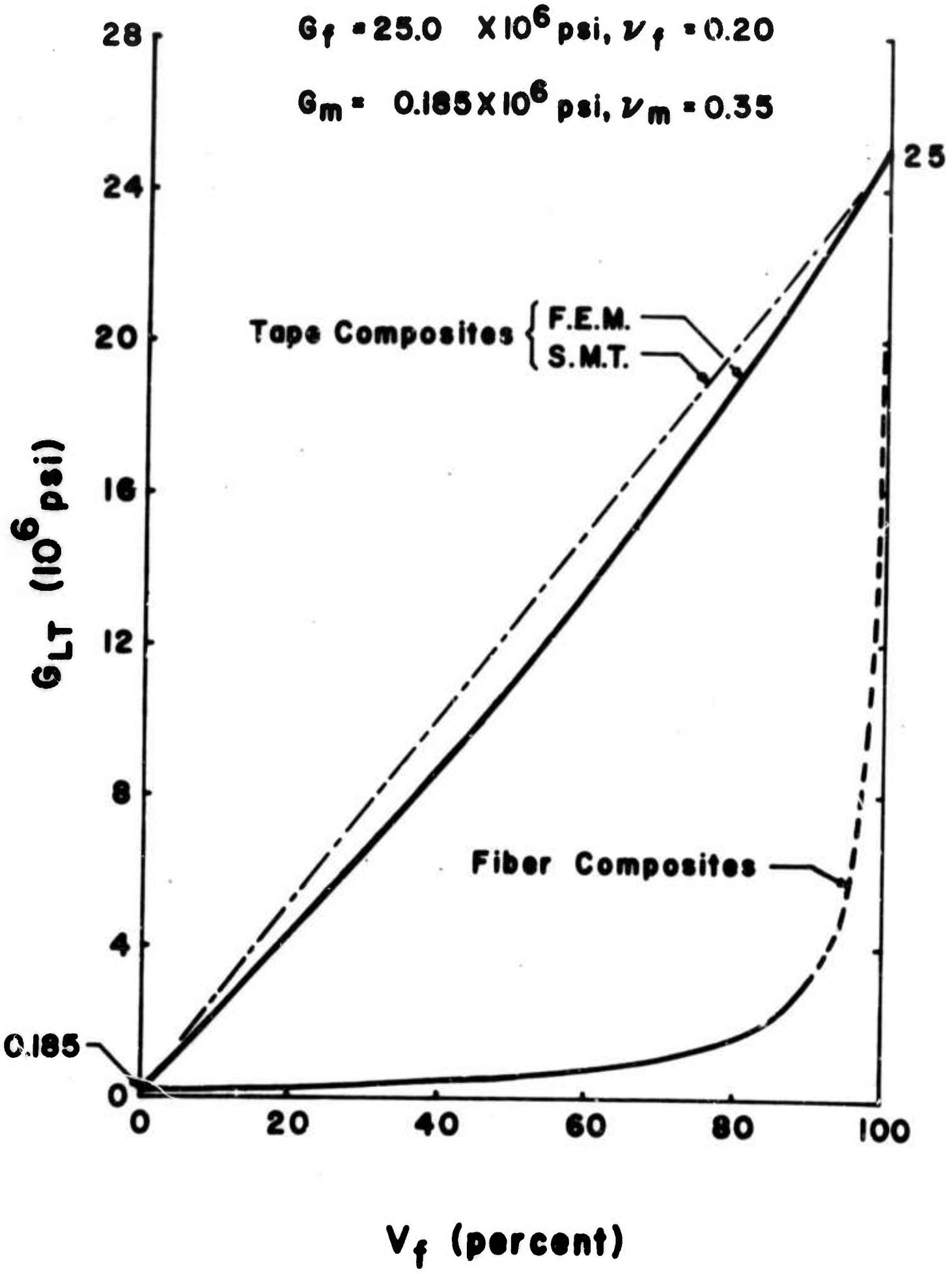


Figure 8

GLASS-EPOXY COMPOSITES

$G_f = 4.34 \times 10^6$ psi, $\nu_f = 0.22$

$G_m = 0.185 \times 10^6$ psi, $\nu_m = 0.35$

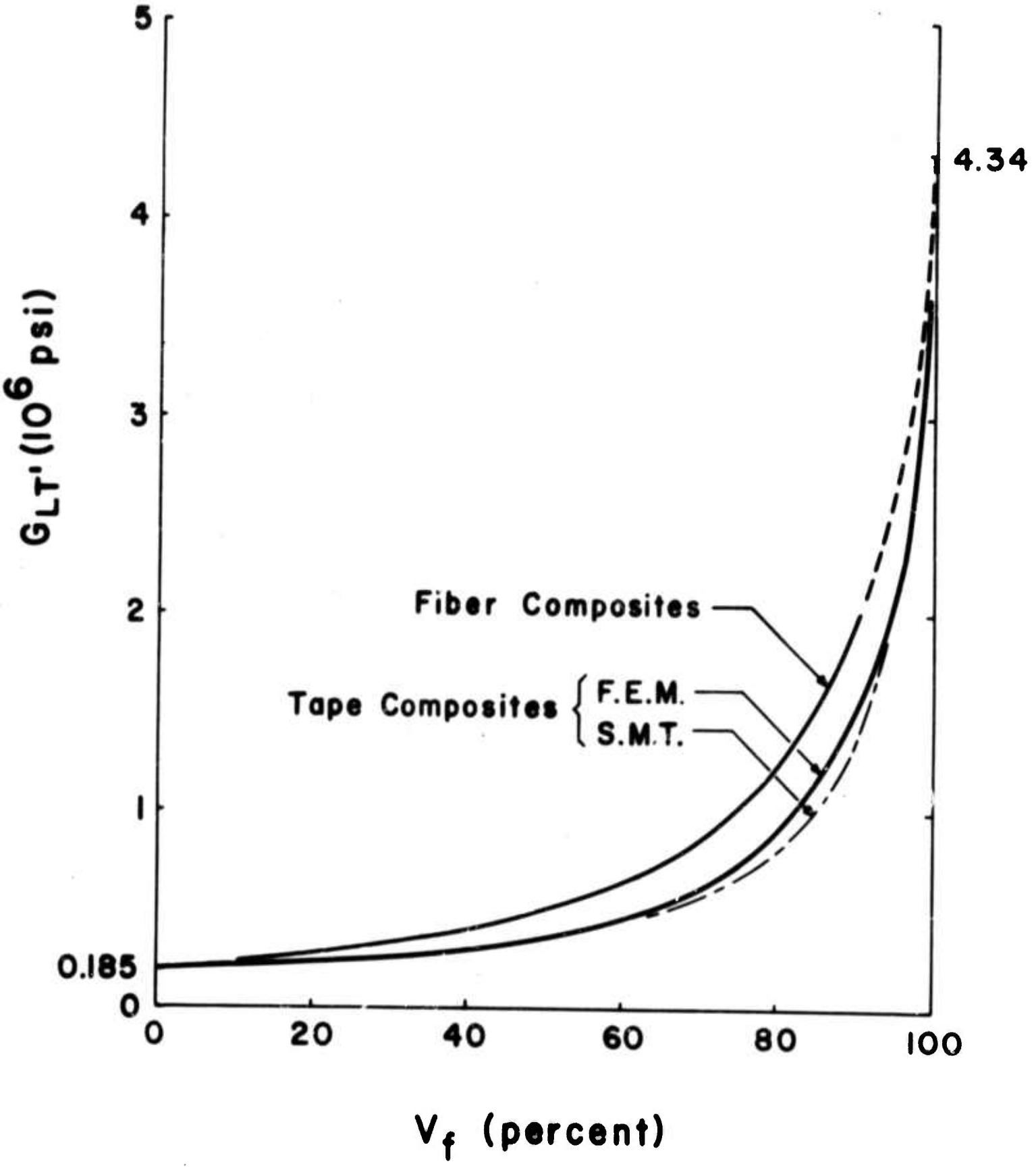


Figure 9

GLASS - EPOXY COMPOSITES

$G_f = 4.34 \times 10^6$ psi, $\nu_f = 0.22$

$G_m = 0.185 \times 10^6$ psi, $\nu_m = 0.35$

$B_m = 0.556 \times 10^6$ psi

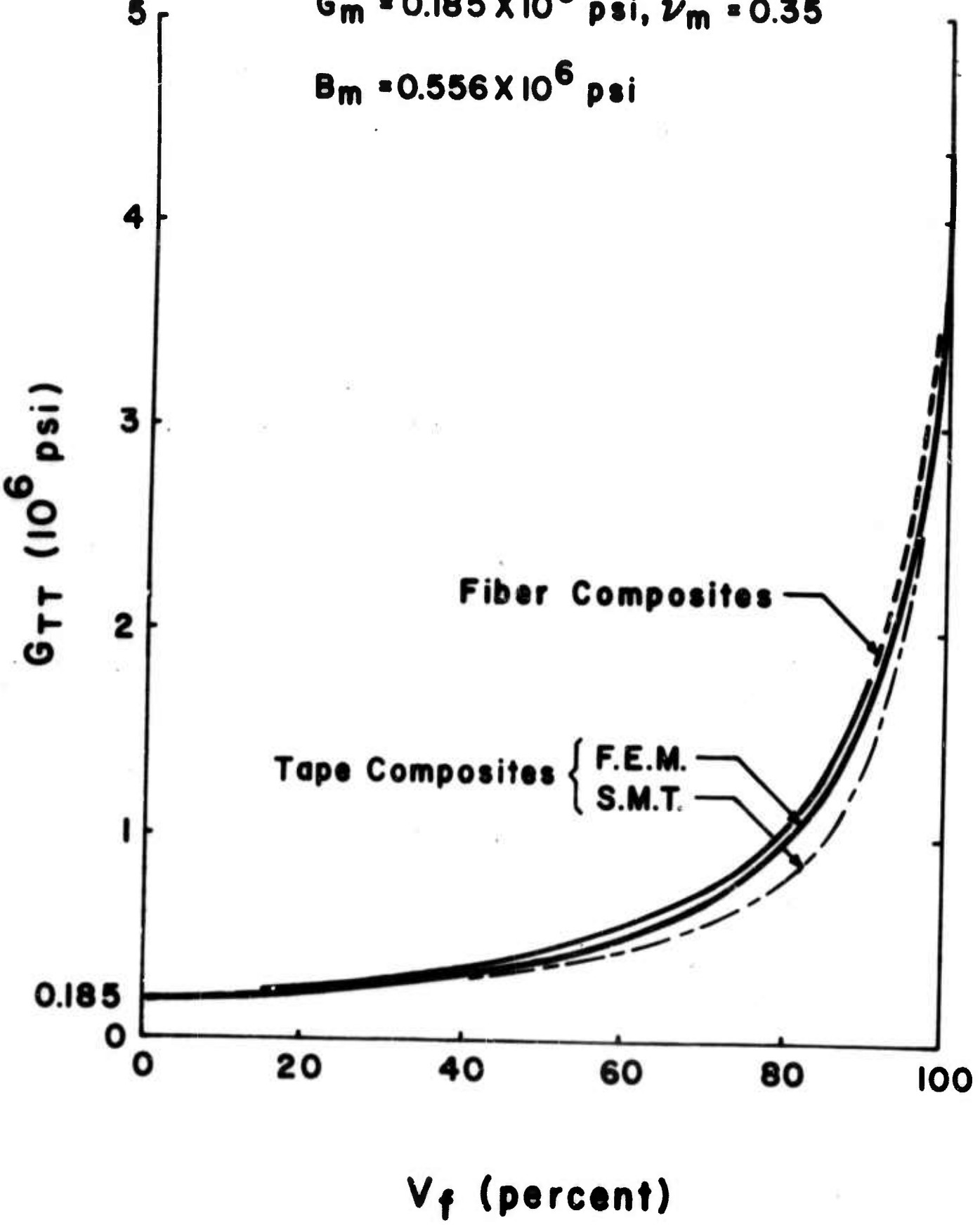


Figure 10

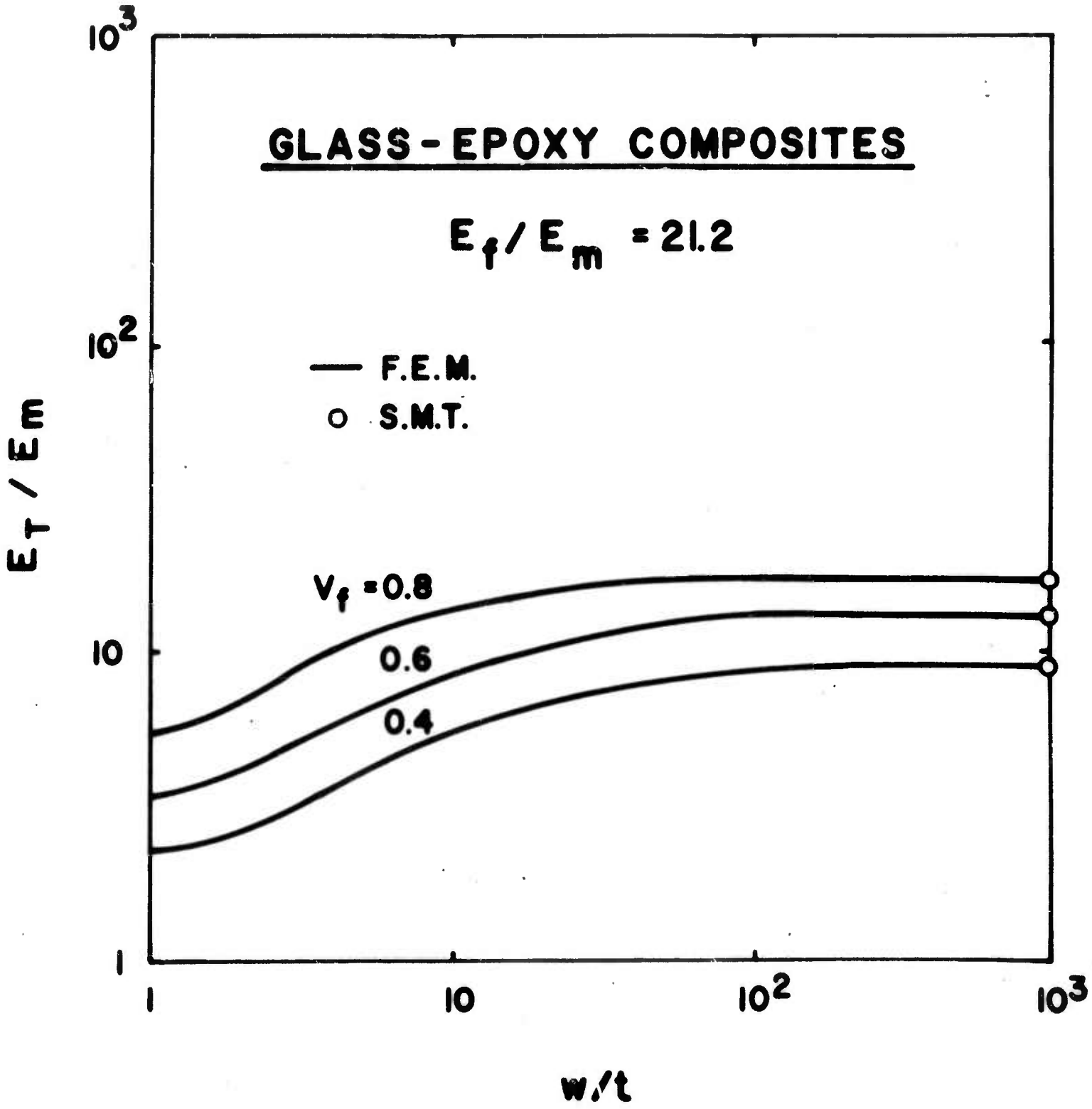

GLASS-EPOXY COMPOSITES
$E_f / E_m = 21.2$
— F.E.M.
o S.M.T.
V_f = 0.8
0.6
0.4
E_T / E_m
w./t
10^3
10^2
10
1
1
10
10^2
10^3

Figure 11

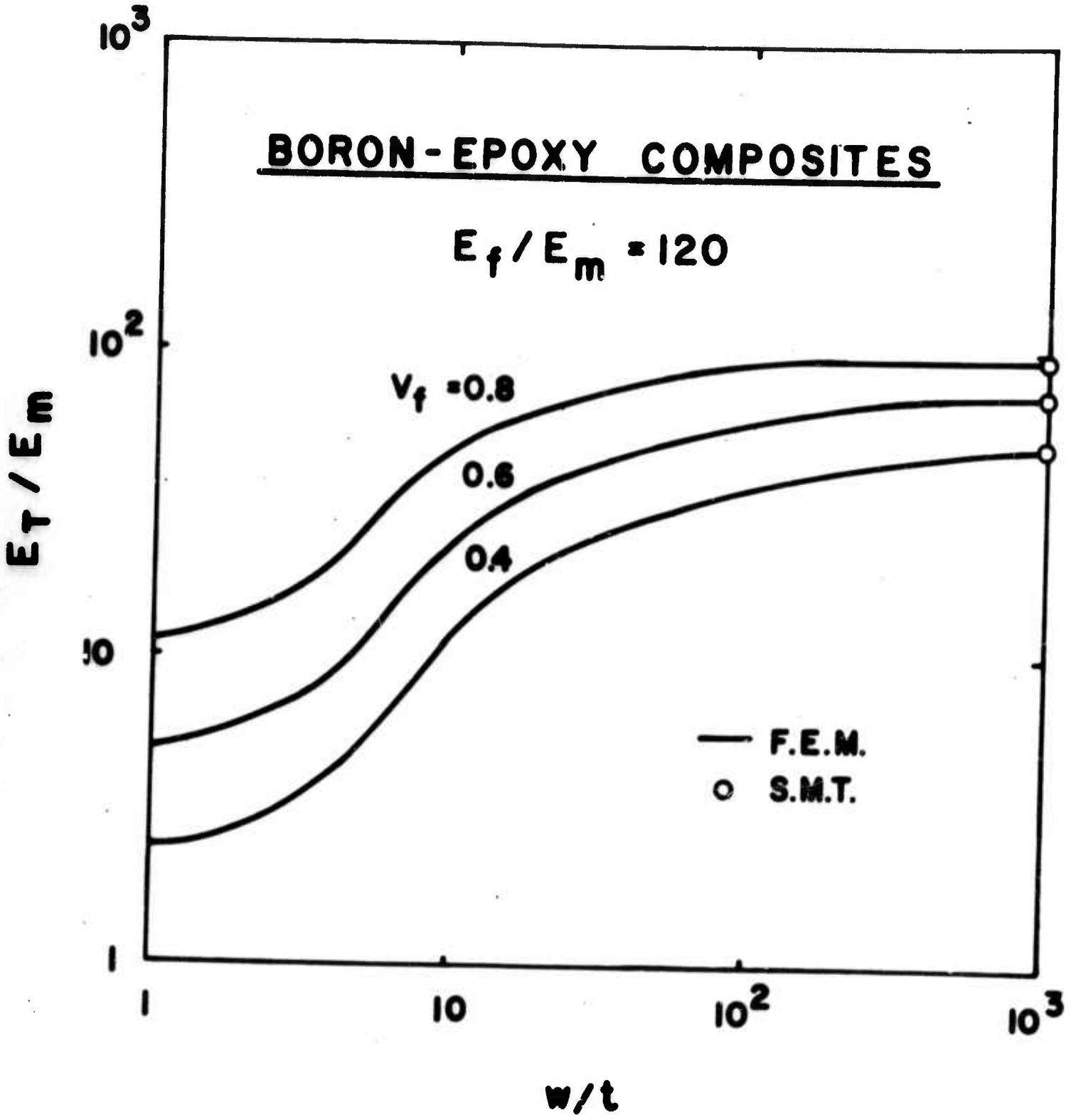

BORON-EPOXY COMPOSITES
$E_f / E_m = 120$
V_f =0.8
0.6
0.4
F.E.M.
S.M.T.
E_T / E_m
w/t
10^3
10^2
10
1
1
10
10^2
10^3

Figure 12

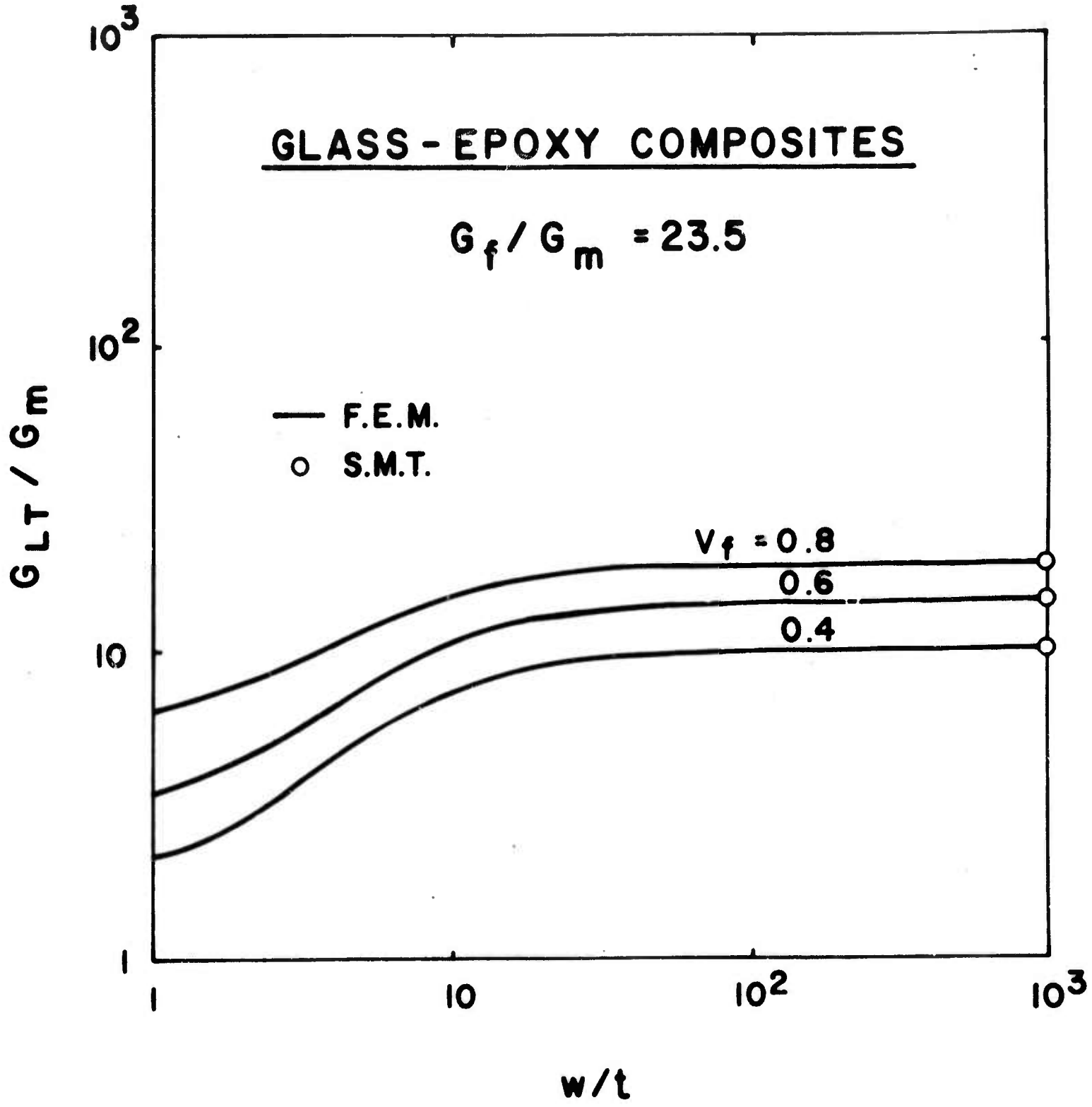

GLASS - EPOXY COMPOSITES
$G_f / G_m = 23.5$
— F.E.M.
o S.M.T.
$V_f = 0.8$
0.6
0.4
G_{LT} / G_M
10^3
10^2
10
1
1
10
10^2
10^3
w/t

Figure 13

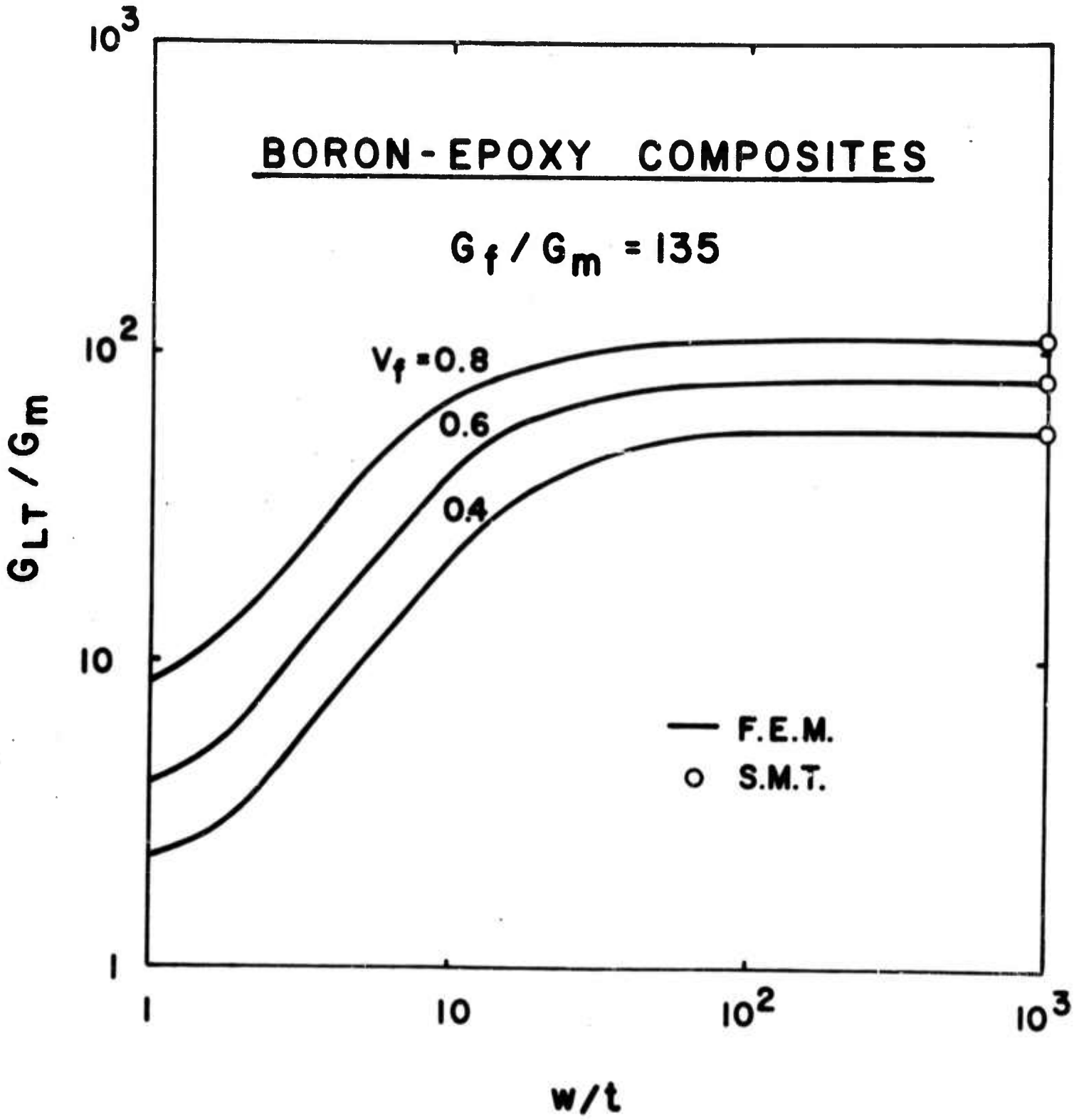

BORON-EPOXY COMPOSITES
$G_f / G_m = 135$
V_f = 0.8
0.6
0.4
F.E.M.
S.M.T.
G_{LT} / G_m
w/t
1
10
10^2
10^3

Figure 14

GLASS-EPOXY COMPOSITES

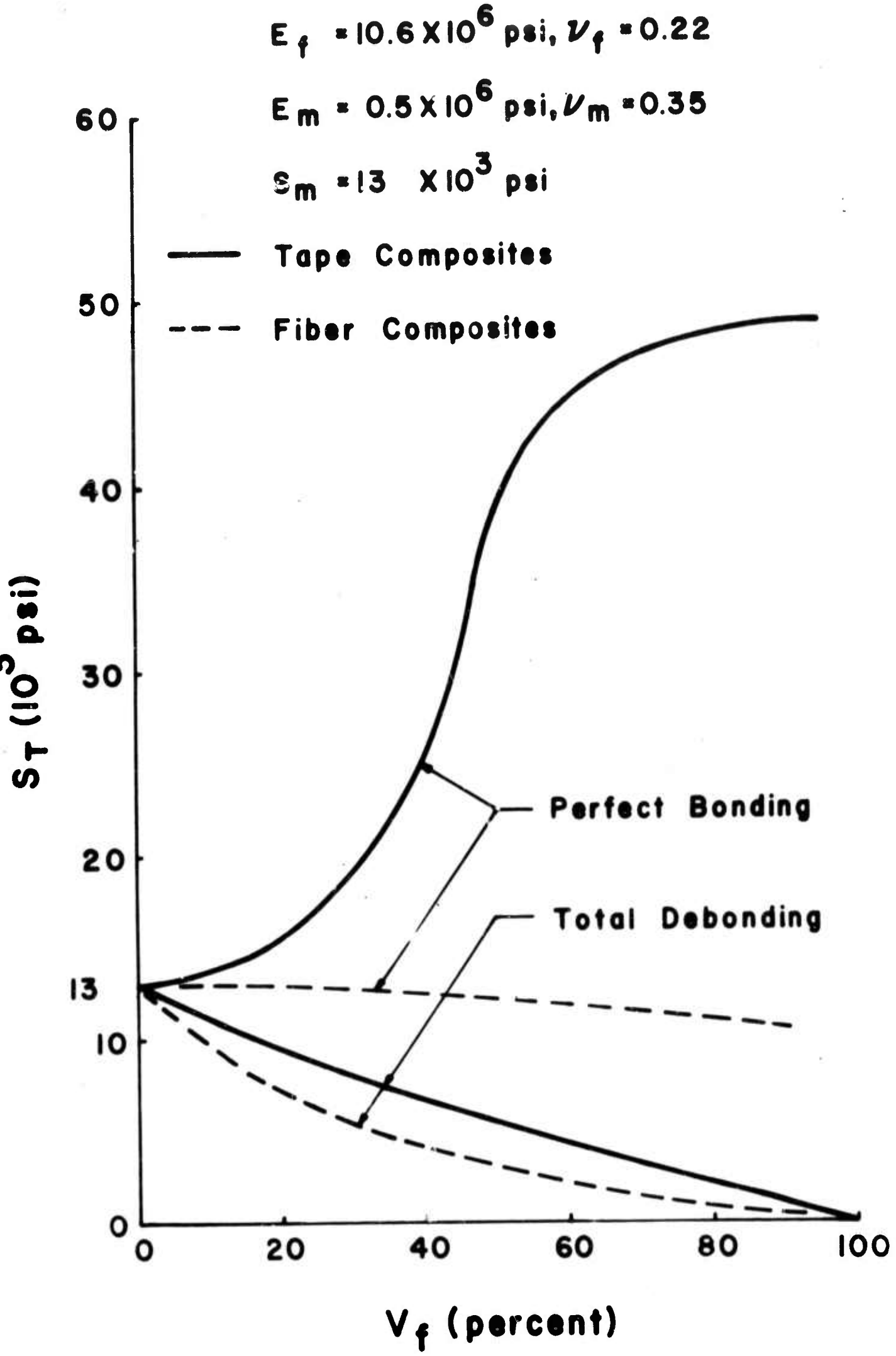


Figure 15

GLASS-EPOXY COMPOSITES

$E_f = 10.6 \times 10^6$ psi, $\nu_f = 0.22$

$E_m = 0.5 \times 10^6$ psi, $\nu_m = 0.35$

$S_m = 6 \times 10^3$ psi

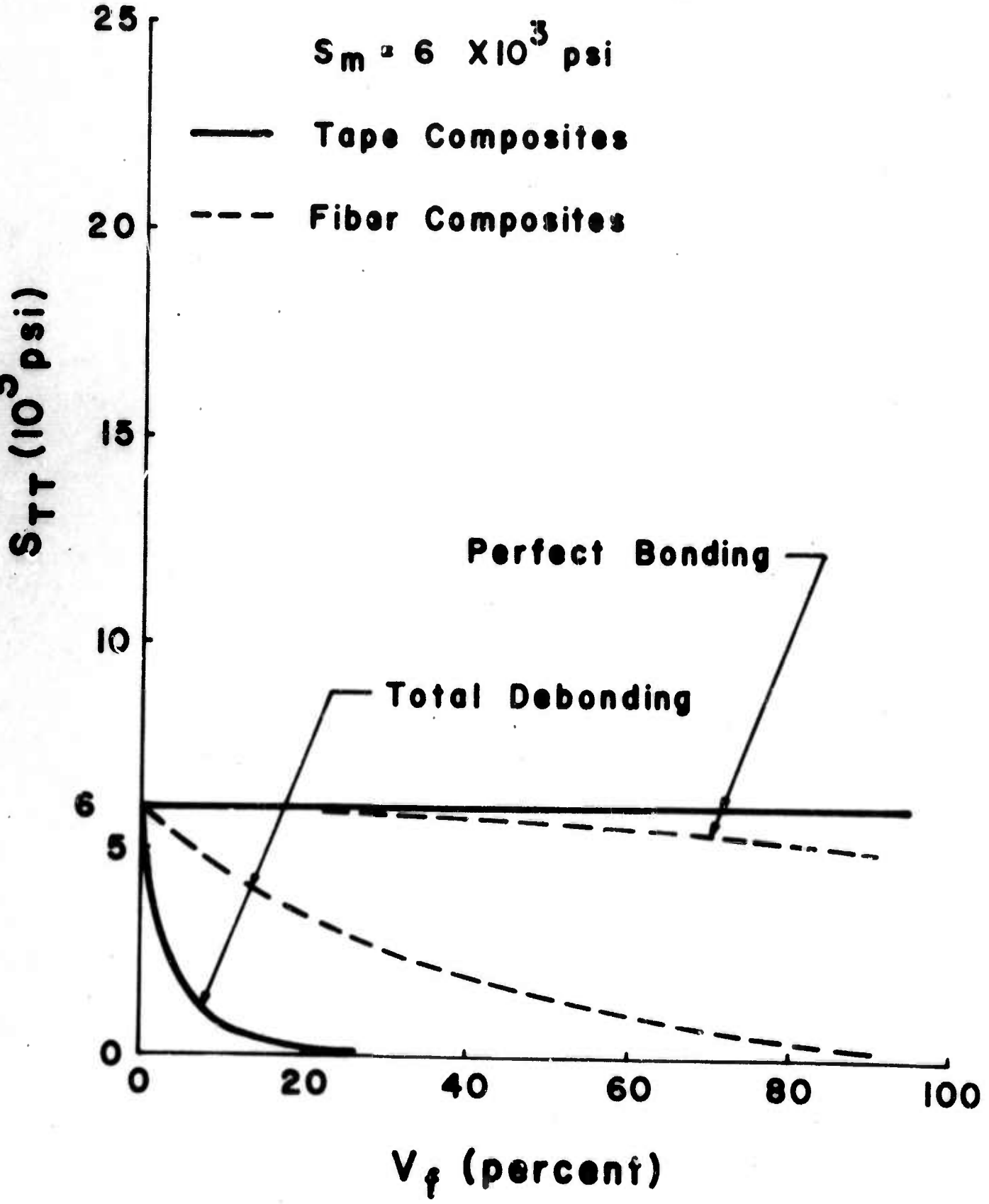


Figure 16

GLASS-EPOXY COMPOSITES

$E_f = 10.6 \times 10^6$ psi, $\nu_f = 0.22$

$E_m = 0.5 \times 10^6$ psi, $\nu_m = 0.35$

$S_m = 6 \times 10^3$ psi

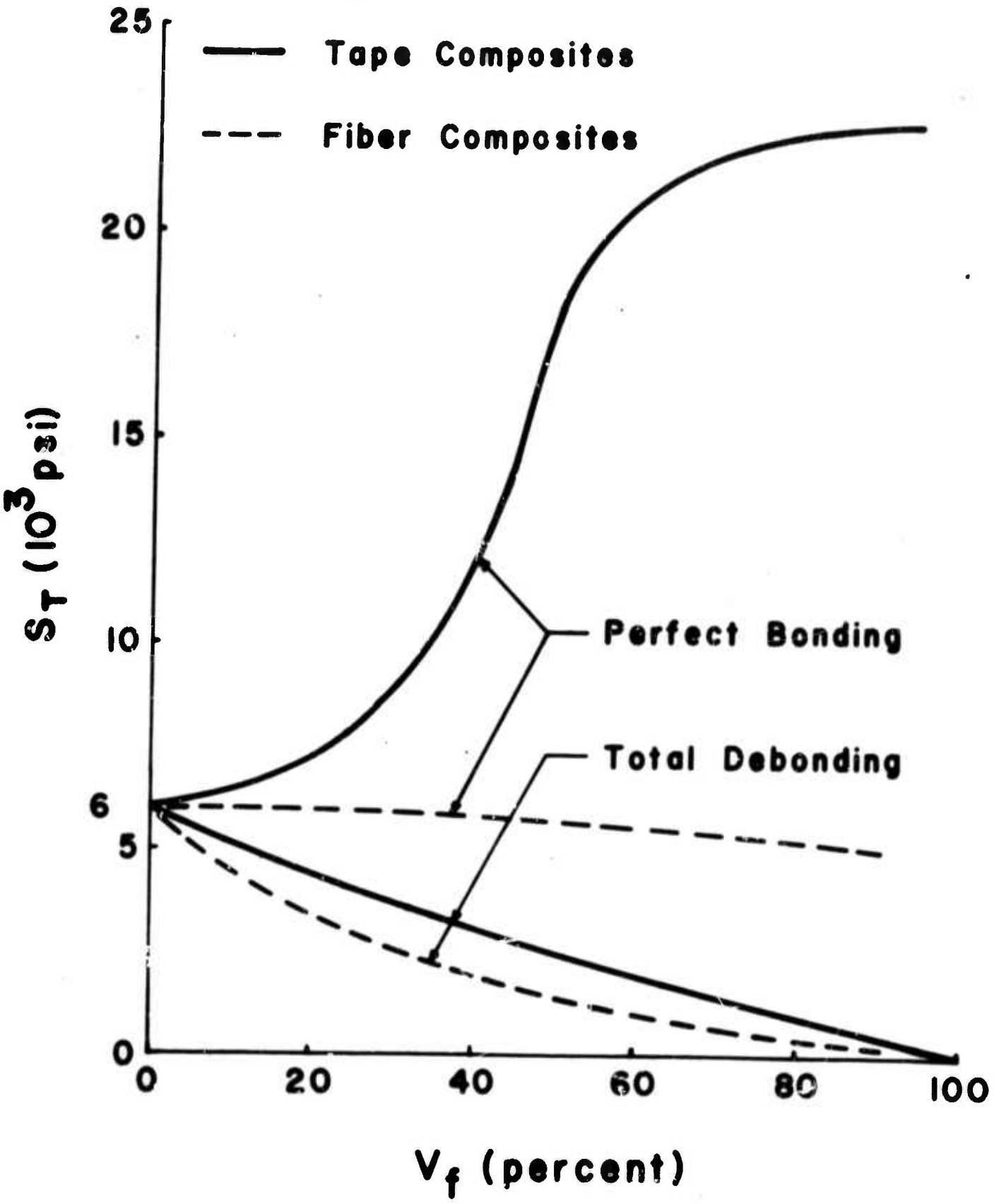


Figure 17

GLASS-EPOXY COMPOSITES

$E_f = 10.6 \times 10^6$ psi, $\nu_f = 0.22$

$E_m = 0.5 \times 10^6$ psi, $\nu_m = 0.35$

$S_m = 13 \times 10^3$ psi

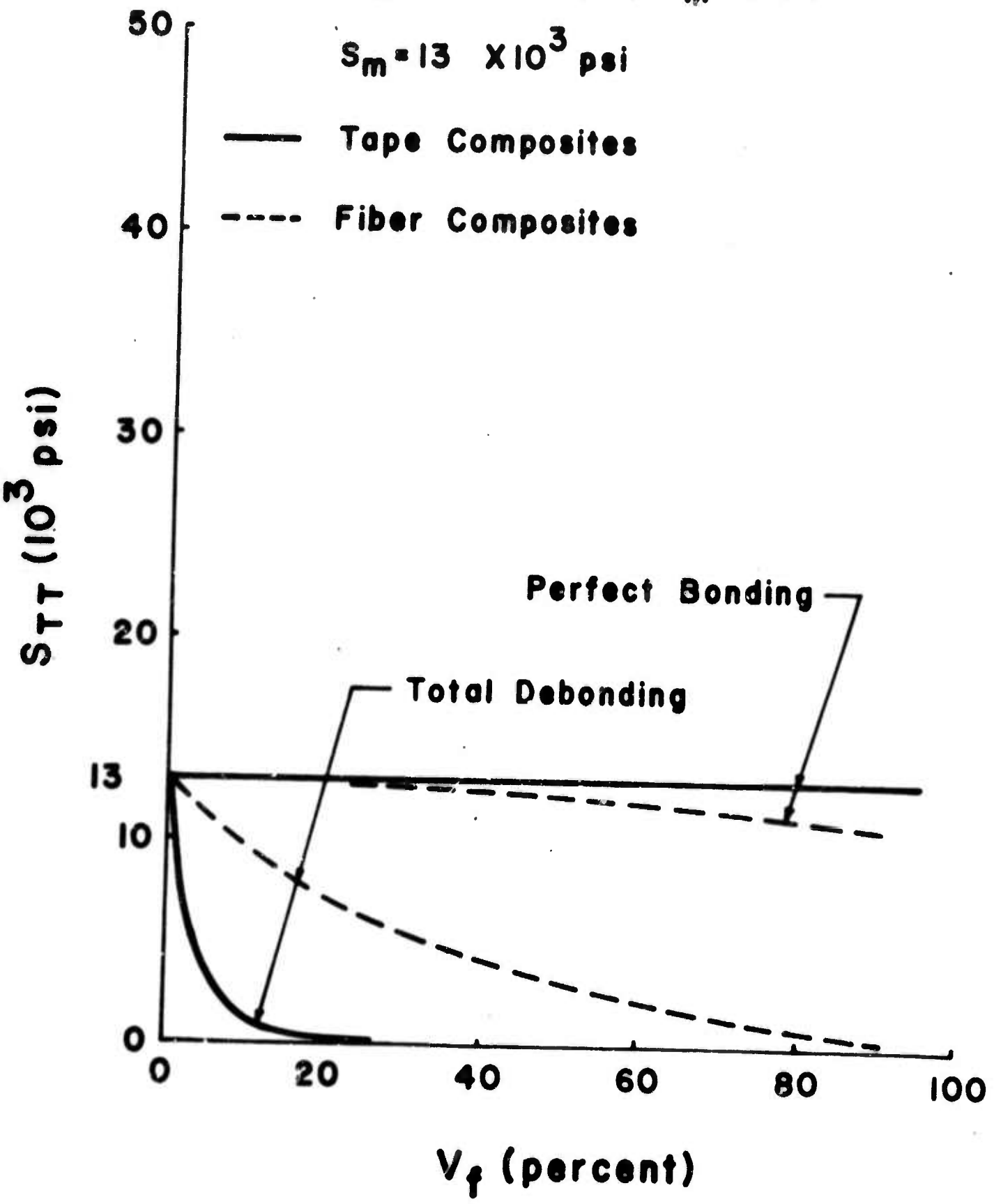


Figure 18

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Monsanto Research Corporation	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Mechanical Properties of Tape Composites

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
P. E. Chen and L. E. Nielsen

6. REPORT DATE October 1968	7a. TOTAL NO. OF PAGES 49	7b. NO. OF REFS 20
8a. CONTRACT OR GRANT NO. N00014-67-C-0218 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) HPC 68-72 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Director of Material Sciences, Office of Naval Research.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research Washington, D. C. 20360

13. ABSTRACT

The stiffness and strength of tape-reinforced composites have been calculated by using the finite-element method, simple model theory and the von Mises-Hencky criterion. The tapes are assumed to be oriented uniaxially in both the longitudinal and transverse directions. According to the theoretical calculations, substantial increases in two basic moduli and a transverse strength are possible with the tape systems, as compared with the corresponding fiber systems. The calculations are based mainly on glass-epoxy composites.

DD FORM 1 NOV 68 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
stiffness						
strength						
modulus						
mechanical properties						
tape-reinforced composites						
oriented tapes						
glass tapes						
boron tapes						
epoxy matrix						
finite-element method						
simple model theory						
von Mises-Kencky criterion						
evaluation						